# SELF COMPACTING CONCRETE CONTAINING POLYPROPYLENE FIBRE AND ITS BEHAVIOUR AS WALL PANEL UNDER CYCLIC LOAD

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**بِسْـمِ اللَّهِ الرَّحْمَـٰنِ الرَّحِيـمِ**

**قُلْ إِنَّ صَلَاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي لِلَّهِ رَبِّ الْعَالَمِينَ (162) لَا شَرِيكَ لَهُ ۖ وَبِذَٰلِكَ أُمِرْتُ وَأَنَا أَوَّلُ الْمُسْلِمِينَ (163)**

In the name of Allah, Most Gracious, The Most Merciful

Say: "Truly, my prayer and my service of sacrifice, my life and my death, are (all) for Allah, the Cherisher of the Worlds: ((162)). No partner hath He: this am I commanded, and I am the first of those who bow to His will ((163)).

The Holy Quran, chapter 6, verse 162-163.

To my beloved parents Asmaa and Qasim in recognition and love for their sacrifices, patience and affection which are beyond description.

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## ABSTRACT

Self-compacting concrete, SCC, is a new innovation of high strength concrete which uses less aggregate, able to flow by itself and does not require compaction. These advantages make it the main choice as precast system which could speed up the construction time with less wastage at the construction site. This research investigated the fresh and mechanical properties of SCC incorporating polypropylene fibre, PPF, and the structural behaviour of precast SCC panel, PSCC, with added PPF subjected to lateral cyclic load. The PSCC panel with dimensions of 2000 mm height, 1000 mm width, and 150 mm thick was tested under lateral cyclic load to study its structural behaviour according to code ACI 318 and ASCE/SEI. A parametric study was conducted on PSCC panels with various slenderness ratios, aspect ratios, and reinforcement areas to study their effects on the panel's structural behaviour by means of finite element method using ABAQUS software, which was validated with the results from experimental work. The results showed that with optimum percentage of 0.05% PPF, SCC mixture showed good consistency and workability. The mechanical properties of SCC was noticed to increase with increased PPF where its mean compressive strength, tensile strength, modulus of elasticity and flexural strength were enhanced by 6%, 27%, 8% and 18%, respectively. It was also noticeable that PPF managed to control the crack propagation while under flexure through minimise the cracks. Under lateral cyclic load, PSCC wall achieved drift levels in increment of 2.1% with no damage appeared before failure. The damage of the wall at failure was limited to its base region due to critical stresses concentrated within this area. It was also noticed that PSCC wall with added PPF achieved higher drift with higher dissipation energy up to 3000 kJ at 2.7 % compared to Ruiz, *et al* wall's which achieved dissipation energy of 700 kJ at 1.3 % drift. Maximum strains recorded on the surface of panel and in the steel reinforcement were observed at the base region which confirms the crack and crush

occurred within this region. Higher slenderness ratio of panel recorded lower ultimate load but higher maximum horizontal displacement and more ductile behavior. Meanwhile, aspect ratio showed the opposite results where lower aspect ratio resulted with higher ultimate load achieved but smaller maximum displacement, where wall behaved in a less ductile behaviour. Higher the reinforcement area recorded higher ultimate load and maximum displacement. However, it is noticed that the reinforcement area did not have any significant effect on the ductility behavior of the panel.

## ABSTRAK

Konkrit mampat sendiri, SCC, adalah inovatif baru konkrit kekuatan tinggi yang menggunakan kurang agregat, dapat mengalir dengan sendirinya dan tidak memerlukan pemadatan. Kelebihan ini menjadikan ia pilihan utama sebagai sistem pratuang yang dapat mempercepat waktu pembinaan dan mengurangkan pembaziran di tapak pembinaan. Kajian ini menyiasat sifat-sifat segar dan mekanikal SCC yang menggabungkan gentian polipropilena, PPF, dan tingkahlaku struktur panel pratuang SCC, iaitu PSCC, tertakluk pada beban kitaran sisi. Panel PSCC dengan dimensi 2000 mm tinggi, 1000 mm lebar, dan 150 mm tebal telah diuji di bawah beban kitaran sisi untuk mengkaji tingkah laku strukturnya mengikut kod ACI 318 dan ASCE / SEI. Satu kajian parametrik telah dijalankan ke atas panel PSCC dengan pelbagai nisbah kelangsingan, nisbah aspek, dan keluasan tetulang untuk mengkaji kesannya terhadap tingkah laku struktur panel dengan menggunakan kaedah unsur terhingga menggunakan perisian Abaqus, yang telah disahkan dengan keputusan dari eksperimen. Hasil kajian menunjukkan bahawa dengan peratusan optimum 0.05% PPF, campuran SCC menunjukkan konsistensi dan kebolehkerjaan yang baik. Sifat-sifat mekanikal SCC telah disedari meningkat dengan peningkatag PPF dimana kekuatan mampatan, kekuatan tegangan, modulus keanjalan, dan kekuatan lenturan telah dipertingkatkan sebanyak 6%, 27%, 8% dan 18% masing-masing. Ia juga adalah ketara bahawa PPF berjaya mengawal penyebaran retak semasa dibawah pengaruh lenturan melalui pengurangan retak yang berlaku. Di bawah beban kitaran sisi, dinding PSCC mencapai pesongan dalam kenaikan 2.1% tanpa kerosakan yang muncul pada panel dinding sebelum kegagalan berlaku. Kerosakan dinding pada waktu kegagalan adalah terhad kepada kawasan tapaknya disebabkan oleh tekanan kritikal yang tertumpu di kawasan ini. Keputusan juga menunjukkan bahawa dengan menambah PPF dalam dinding PSCC dapat mencapai pesongan lebih tinggi dengan pelepasan tenaga yang lebih tinggi sehingga 3000 kJ pada 2.7% berbanding dengan

dinding Ruiz et al. yang mencapai tenaga pelesapan 700 kJ pada 1.3% pesongan. Ketegangan maksimum yang dicatatkan pada permukaan panel dan tetulang keluli pada kawasan tapak panel mengesahkan retak dan hancur yang berlaku pada kawasan ini. Nisbah kelangsingan yang lebih tinggi pada panel mencatatkan beban muktamad yang lebih rendah tetapi anjakan mendatar maksimum yang lebih tinggi dan lebih berkelakuan mulur. Nisbah aspek menunjukkan keputusan yang bertentangan di mana nisbah aspek yang lebih rendah menyebabkan beban muktamad yang lebih tinggi dicapai tetapi anjakan maksimum yang lebih kecil, dimana dinding berkelakuan dalam tingkahlaku yang kurang mulur. Lebih tinggi keluasan tetulang mencatatkan beban muktamad yang lebih tinggi dan anjakan maksimum. Walau bagaimanapun, adalah didapati bahawa kawasan tetulang itu tidak mempunyai apa-apa kesan yang signifikan terhadap tingkah laku kemuluran panel.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| $c/c$ | - | centre to centre |
| $C$ | - | Thermal efficiency |
| W | - | Length of the wall |
| D | - | Damage parameter |
| E | - | Young's Modulus |
| H | - | Height of panel |
| H/W | - | Aspect ratio |
| H/t | - | Slenderness ratio |
| t | - | Overall Thickness |
| $\Psi$ | - | Dilatation angle |
| $E$ | - | Eccentricity |
| $\sigma$ | - | Stress |
| $\varepsilon$ | - | Strain |
| $\upsilon$ | - | Poisson Ratio |
| ASTM | - | American Standard Test Method |
| BS | - | British Standard |
| CIDB | - | Construction Industry Development Board of Malaysia |
| CREAM | - | Construction Research Institute of Malaysia |
| C3D8R | - | Continuum three-dimensional 8 node linear brick element |
| FE | - | Finite element |
| FEA | - | Finite Element Analysis |
| IBS | - | Industrialized Building System |
| LVDT | - | Linear Voltage Displacement Transducers |
| PCI | - | Precast Concrete Institution |
| PSCC | - | Precast Self compacting concrete |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Conventional construction has recently become unattractive method for housing construction due to its massive waste generated, unsustainability and excessive expenditure of resources [1]. This has put endeavoured efforts into implementing an economic and constructive alternative for that old system. In Malaysia, Construction Industry Development Board (CIDB) has moved on to adopt a new construction system for housing construction in the early of 1960's which is known as the Industrialised Building System (IBS). It is a construction system that can be built using pre-fabricated components of beams, walls, roofs and floors. IBS is one of the innovations considered as a solution in the development of new technology in the construction industries. IBS uses technologies which include building prefabricated components system and on-site installation. It has been in existence since 1960 [2]. The manufacturing process of the components is systematically completed using such sophisticated machinery, formworks and other forms of mechanical equipment that could reduce the labours as minimum as possible. The components can be manufactured off-site or on-site and once completed will be transported to construction sites for assembly and erection [3]. It is believed that the fundamental scheme of utilising IBS is to move some construction effort away from on-site to the manufacturing floor, which would offer several advantages such as reducing the construction time, improving the site management and diminishing wastage [4]. One

of the IBS applications is precast concrete wall panel that offers faster erection and higher quality products [5].

## 1.2 Background of study

Lack of affordable housing has been a major problem around the world that could be caused by limited land for construction, fast need of houses due to disaster, and number of populations which have been increasing year by year. Precast concrete panel is an advanced technology which has been proven to speed up the construction with less wastage at the construction site. Figure 1.1 shows the typical precast reinforced concrete panel and its construction.

There have been many reviews on the performance of precast concrete panel which were fabricated from many various materials. However, the research conducted was mainly focused on the performance of precast panel subjected to in-plane static axial, eccentric load [6-8] and flexure load [9, 10]. Meanwhile, studies on precast structures under cyclic load were mostly conducted on precast reinforced concrete frame [11], its behaviour of connection due to seismic loading [12, 13] and precast conventional concrete wall due to cyclic load [14]. From the reviews conducted, it is concluded that precast panel has high potential to be implemented as structural element not only under static load, but also has a great potential to sustain more critical loads. For example, during the 1988 Armenia earthquake, poorly designed and constructed buildings that incorporated precast concrete walls as the main lateral force resisting system performed substantially better than buildings built with other structural systems. Buildings where lateral force-resistance was provided by structural walls also showed excellent performance during the 1985 Chilean earthquake [15].

As such, this research undertook experimental testing and FEM simulations to study the structural behaviour of precast panel made of self-compacting concrete (SCC) incorporating with polypropylene fibres (PPF), subjected to cyclic load.

Self-compacting concrete (SCC) does not require vibration. It is able to flow under its own weight, completely filling formwork and achieving full compaction. In this study, the fresh and hardened properties of precast self-compacting concrete panel (PSCC) incorporating PPF were investigated. From this investigation, the

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